Ballistic and Lifting Nano ADEPT - Flight Testing for Mission Infusion Opportunities

A Briefing to OPAG

Ethiraj Venkatapathy

on behalf of: Paul Wercinski, Project Manager

Paul.F.Wercinski@nasa.gov
650-604-3157

August 2016
ADEPT SR-1 & Lifting Nano ADEPT

**SR-1 Features**
- 0.7m deployed diameter
- 8 ribs, 70 deg symmetric shape
- 4 layer carbon fabric system
- Unguided, ballistic entry
- Sounding rocket payload
  - 125 km apogee (Mach 3 peak)
  - Negligible aerothermal heating
- Simple, dual spring deployment system
- Free fall, ground impact, on-board data recovery

**LNA Features**
- 1.0m+ deployed diameter
- 12 ribs, 70 deg asymmetric shape with trim tab
- 6 layer carbon fabric system
- L/D = 0.19 (AoA = 11 deg), Guided hypersonic flight
- LEO Secondary payload (ULA Centaur ABC)
  - 7.6 km/s entry from LEO (Mach 27 peak)
  - Aerothermal heating (>100 W/cm², 3.5 kJ/cm²)
- Electro-mechanical deployment system
- Parachute terminal descent, air-snatch recovery
1. Yo-Yo De-spin

2. Separate Nose & Booster

3. ADEPT Ejection (~100 km prior to apogee)

4. Deployment

5. Re-entry
   M=3.1
   Peak Decel= ~4 g
   Dyn Pres= ~0.7 kPa
   Nominal is chuteless descent
   Impact Velocity ~ 25 m/sec

6. Recovery in WSMR (C-band transponder & GPS locator)

Launch from SpaceLoft XL SR
From White Sands
Problem / Current Solution:
• Large payload delivery to Mars Surface requires guided lift capability to support aerocapture and precision EDL concept of operations
• New capabilities for science missions to other planets (Venus, Titan, Mars) provided by Lifting ADEPT architecture
• Design of the mechanical deployable ADEPT for lifting configurations able to execute hypersonic guided flight
  • Demonstrate low L/D deployable capable of relevant heating environments

Proposed solution:
• Perform design studies of an Earth flight test (LEO) of an asymmetric shaped Nano (1m class)-ADEPT
• Leverages design experience from ADEPT SR-1 sounding rocket flight test

FY16 LNA Study Schedule

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Con-Ops Overview

Lifting Nano ADEPT Vehicle Concept
Additional Charts for Poster Presentation
1m ADEPT Mission Pull (Discovery class)

**Venus**

Science Pull:
- Delivery of In-situ atmosphere science instruments.
- Achieve low deceleration loads for sensitive instruments

**Mars**

Science Pull:
- Global distribution, low cost
- Numerous landers

Dandelander (Malin SSS):
Cubesat distributed surface network concept

**Earth**

LEO Return: Secondary on Upper Stage, ISS Downmass or free-flyer on Super Strypi class LV

- De-orbit Capability
- 22 N thruster incorporated with green propellant
- 6 ea, 3U slots for subsystems or payloads

**Titan**

- Lifting ADEPT configuration allows aerocapture at Titan, effective thermal control with open-back configuration

Project Pre-Decisional Not for Distribution without ADEPT Project Approval
ADEPT Flight Test Timeline

2017

SR-1
- 0.7m 70deg Ballistic 15kg
- SR-125km apogee (Mach3)

ORB-1
- 3.5m ACV L/D=0.25 150kg
- LEO, Guided hypersonic flight

ORB-2
- 8m ACV L/D=0.25
- LEO or GTO, Guided hypersonic flight
- Earth Demo Exploration-Class EDL Ops and Mars Entry Environments

Nano-Lifting ADEPT CIF 2016

2020

Mars Small (5kg) network landers

ORB-2

2023

SR-2
- 2.3m ACV L/D=0.25 80kg
- SR-450km apogee (Mach7)

2026

Titan Aerocapture

Venus in-situ Atmosphere science

ORB-1
- 16m ACV L/D=0.25
- Dual Pulse Aerocapture and EDL Capable
- Delivers 20 MT Payload

Mars-1
ADEPT is an atmospheric entry architecture for missions to most planetary bodies with atmospheres.

- Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Low ballistic coefficient (< 50 kg/m²) provides a benign deceleration and thermal environment to the payload.
- High-temperature ribs support 3D woven carbon fabric to generate drag and withstand high heating.
Current Focus on 1m ADEPT

Sounding rocket payload mock-up:
Stowed and deployed 0.7m configuration compatible with UP Aerospace payload cannister geometry

Payload volume (2U shown for example)
Avionics unit (IMU, GPS, solid memory, power)
Spring-deployment system
Struts
Shoulder stitching treatments
Stitched and resin-infused seams
3D woven carbon fabric
Ribs tension fabric with pockets at tips (like an umbrella)
Each test campaign provides system knowledge in more than one system attribute, and many system attributes are explored by more than one test.
Proposed Sounding Rocket (Mach 3) Flight Test
August 2017 Launch

• OBJECTIVE:
  – Demonstrate LV separation and exo-atmospheric deployment.
  – Characterize aerodynamic performance from supersonic to subsonic flight regimes.

• APPROACH:
  – Demonstrate ADEPT 1 m class system flight performance. TAYF: FAYT

• IMPACT:
  - Provide flight test experience for ADEPT configuration.
  - 70deg sphere cone flight supersonic - subsonic
  - Critical first step in integrated flight hardware experience for EDL Pathfinder architecture assessments

✓ Approved (July 2014) as directed payload from Flight Opportunities Program
SR-1 DESIGN UPDATE (Cfg. 3.2)
STOWED

1st stage (long travel)springs

Nose cap
Ribs
Rib tips
Stowed retention
-> release
GPS patch antenna

Impact attenuation

2nd stage trigger & deployment latch pins

(fabric not shown)
Deployment carriage w/ 2nd stage springs

Avionics Box

Onboard Equip:
- Camera
- Transponder
- Sensors

Carbon fabric “skirt”

Linear guides

DESIGN UPDATE (Cfg. 3.2)
DEPLOYED
# ADEPT SR-1 Schedule
## Aug 2017 Launch

<table>
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<tr>
<th></th>
<th>FY 2016</th>
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<th>FY 2017</th>
<th></th>
<th>FY 2018</th>
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<tr>
<td></td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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<tr>
<td><strong>ADEPT SR-1 Key Milestones</strong></td>
<td>▲ SRR</td>
<td>▲ PDR</td>
<td>◆ CDR</td>
<td></td>
<td>◆ SR-1 Ship</td>
<td>▲ UP Aero CST</td>
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<tr>
<td><strong>SR-1 Prototype and Flight Hardware Design and Test</strong></td>
<td>Data and Power Trades Close</td>
<td>Flight Mechanics Parameters and Trajectory Events Defined</td>
<td>Trajectory Reconstruction Process and Dispersions</td>
<td>SR-1 Sep System Verification Test at UP Aero (CO)</td>
<td>Flight Unit Drawings Released</td>
<td>Fabrication &amp; COTS component procurement</td>
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LNA Concept (v3) – Features
(70 deg sphere-cone w/ trim tab)

- 6-layer Carbon Fabric
- "Standard" ADEPT Rib Tips
- "12 Pack" Cubesat Payload
- 12 Ribs (8 normal, 4 long)
- 12 Struts (All the same)
- Mounting & Separation Ring (Notional: 11.76" Lightband)
- Prop Modules
- Mainbody extension (For travel & to clear ribs)
- Moving Aft Ring
- 4 Linear Actuators w/ guide rails
- Mainbody extension (For travel & to clear ribs)
### Atlas V Aft Bulkhead Carrier (ABC) Rideshare Payload Accommodation

<table>
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<tr>
<th>Description</th>
<th>An interface located at the aft-end of the Atlas V Centaur second-stage</th>
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<tbody>
<tr>
<td>Vehicle</td>
<td>Atlas V</td>
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<tr>
<td>Capacity</td>
<td>1 ABC per Atlas V</td>
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<tr>
<td>Interface</td>
<td>15-in Bolted Interface</td>
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<tr>
<td>Mass</td>
<td>80 kg (176 lb)</td>
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<tr>
<td>Volume</td>
<td>51 cm x 51 cm x 86 cm (20 in x 20 in x 34 in)</td>
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<tr>
<td>Status</td>
<td>Operational; first launch 09-2012 on NROL-36 (OUTSat - NPSCuL box with 8 P-PODs)</td>
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A second ABC mission, GEMSat, launched in Dec 2013, and two additional missions are currently on contract for launch by ULA.

5/25/16
ISS Resupply 51.6° Orbit
Kwajalein / RTS Feasibility

- Roughly Annual ISS Launch Opportunities
- Conditions
  - 51.6° inclination orbit from KSC
  - Assume 500 nmi vehicle capture radius
  - 12 nmi ‘Broad Ocean’ boundary
  - LNA Concept V1
- Relevant Results
  - Requires 4 orbits (~6 hrs) to overfly Kwajalein
- Need to know
  - Range of recovery aircraft
  - Required overflight altitude
    - How early can we reenter?
  - EFPA / $V_i$ relationship
- Notional Ellipse Assumptions
  - No entry error
  - No breakup (no change in $C_L$, $C_D$)
  - ‘Worst’ case scenarios
    - Fixed 10°, 15° AoA
    - $V_i = 7.89$ km/s
    - 5°, 7° EFPA
    - Max cross range (62, 102 km)
    - Min down range (573, 563 km)
    - Max down range (1130, 1340 km)

Kwajalein / RTS is feasible depending on overflight restrictions
Optimized Out-and-Back Trajectory

- **Vehicle Model**
  - Aero data provided by ARC
    - LNA Concept V1
  - Bank as control (+/- 180°)
  - 15°/s bank rate limit
  - \( m = 40 \text{ kg} \)
  - Fixed 10° AoA
- **Conditions**
  - Approximate LEO reentry
  - Interface velocity, \( V_i = 7.42 \text{ km/s} \)
  - Interface altitude, \( H_i = 120 \text{ km} \)
  - EFPA, \( \gamma_i \) = optimized (from 1-7.5°)
  - Final velocity, \( M_f = 1.8 \)
- **Heating Constraints:**
  - Heat flux: 200 W/cm\(^2\)
  - Heat load: 4.5 J/cm\(^2\)
- **Objective:**
  - Max in-flight cross range
  - Zero end of flight cross range
- **Relevant Results**
  - EFPA (\( \gamma_i \)) = 4.32°
  - Heating constraints satisfied

Trajectory demonstrates divert and recovery capabilities
Carbon fabric has been tested over 200 W/cm² in earlier ADEPT arcjet tests.
- C-PICA has been tested over 500 W/cm².
- TPS material response expected to be low/med risk for LNA using conservative TPS thickness allocations.
• ADEPT 1m development has strong potential SMD mission infusion. Small payload delivery to Mars surface, In-situ atmosphere science at Venus, Aerocapture at Titan and outer planets

• System level testing in Arcjets and with Sounding Rocket using common configuration – Huge Challenge for EDL!

• LNA Study on schedule to meet CIF study objectives at end of FY16

• LNA Team (NASA Ames – JHU APL) is working very well together
  – Team skills and experience are a great fit!
  – Excellent communication
  – Team is highly motivated to develop a feasible, yet challenging flight test experiment

• Continued Investment including ADEPT Flight Testing will Enable:
  – Highly visible, flight test experience advances confidence and reduces implementation risk for ADEPT entry architecture
  – Characterization and experience using ‘real hardware’ performance applied to larger scale ADEPT applications
  – SR-1 Flight Experiment is key step to subsequent ADEPT demonstration of guided lifting flight

• Lifting Nano ADEPT is a logical next step from SR-1 (Mach 3) flight experiment for maturing the ADEPT technology architecture
LNA Flight Test Objectives (v1.1)

**Test Objectives (Primary):**

- Demonstrate *exo-atmospheric deployment* of 1m class lifting nano-ADEPT (LNA) in a flight configuration, and maintain the *deployed shape* under flight conditions.

- Demonstrate LNA configuration maintains a *stable orientation* and is capable of performing *closed-loop guided hypersonic maneuvers*.

- Demonstrate that the LNA configuration can survive aerothermal heating rates and heat loads associated with LEO entry conditions.

**Test Objectives (Secondary):**

- *Obtain flight position and attitude data* to enable reconstruction of best estimated trajectory.

- Show that *fabric behavior and surface features* of the ADEPT aeroshell are robust and retain integrity.

- Recover LNA post-flight to recover payloads and assess overall vehicle performance.
Project Background

ADEPT FY12-FY13
- STMD Game Changing Development Program
- Focus on 6m Venus DRM (Delivery of 1000kg lander with peak decel < 30 g’s)
- Carbon fabric arc-jet tested 100-240 W/cm².
- Successful demonstration of 2m Ground Test Article

ADEPT FY14
- Continue 6m Venus focus, Demonstration carbon-fabric stitched joint
- Mid-year budget reduction forced project re-plan to 1m scale
  - Potential for ‘cubesat class’ secondary payload mission infusion
  - Cost effective approach for key system-level demonstrations

ADEPT FY15
- Continuation of ‘FTE-only’ project status
- Focus on 0.7m aero-loads wind tunnel test & 0.35m SPRITE-C Pathfinder arcjet test
- Limited development efforts for 0.7m sounding rocket flight

ADEPT FY16
- 0.7m development continuing under Task agreement (4 FTEs)